Management of Human Error in a Safety Case using Bowtie - A case study

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This paper provides information on a pilot study aimed at the application of the Bowtie risk management methodology for the treatment of human errors in a Safety Case for a Chlor-Alkali production facility with membrane electrolysis under construction. It followed the recommendations contained in the new CCPS/El Concept Book regarding management of human errors through layered Bowties. The study considers the conduct of Human Factors Bowtie Workshops based on draft layered Bowties as a means of facilitating understanding of human factors and involvement of Operator's personnel in the management of human errors during the execution of day-to-day activities, thus ensuring that a high quality, usable and fit-for-purpose Safety Case is delivered.

Keywords: Human errors, Safety Cases, Bowtie

1. Introduction

An Operator of a Chlor-Alkali production plant under construction, prepared a Safety Case production plan (SCPP) to comply with Safety Case regulations in force. Even though the conceptual plant design was already complete, and the plant was in an advanced stage of construction, it was believed that starting the production of a Facility Safety Case (FSC) at this stage would still bring significant benefits for the Operator.

In addition to fulfilling regulatory requirements, it was felt that the Safety Case production process with the active involvement of the Operator's personnel would significantly enhance existing knowledge within the Operator's organization of the major hazard aspects of the facility. In addition, the barriers and controls in place to prevent major accidents and limit their consequences to people and the environment and awareness of the role that human and organizational factors play in the occurrence of major accidents could be identified at an early stage.

Thus, the SCPP covered both administrative and technical aspects associated with the production process and identified all tasks needed to produce ´key´ deliverables containing the required demonstrations, evidences and information for each of the following constituent parts of the FSC:

- Part 1. Introduction
- Part 2. Facility Description
- Part 3. Description of the Safety Management System
- Part 4. Major Hazard Management Process
- Part 5. Emergency Management
- Part 6. SCE Assurance and Verification

For Part 4 – the ´cornerstone´ of the Safety Case - the SCPP addressed all tasks and ´expected´ deliveries derived from the execution of the Major Hazard Management Process, according to the steps indicated below:

- Step 1: Major Hazard Identification
- Step 2: Major Accident Risk Estimation
- Step 3: Identification and assessment of adequacy of control measures
- Step 4: Demonstration of ALARP

The Operator was aware of known Safety Case shortcomings around human and organizational factors and the management of human errors in safety assessment, and decided to scope Step 3 in a way to address the management of risk of human errors. Even though many detailed operational and maintenance procedures were non-existent or too general, with critical operational plant areas such as the control room still under construction with important control and monitoring equipment not yet installed, the Operator decided to deal with human factors issues up-front for the following reasons:

- This would allow identification of any missing information necessary to provide required demonstrations in the operational safety case
- This would serve as a 'road map' or guidance providing the Operator with the 'know-how' necessary to undertake more detailed task analysis to produce the operational safety case.

- Identified shortcomings and recommendations would be dealt with promptly to ensure completeness of the demonstrations required for the safety case.

To provide the right perspective and knowledge needed to carry out the task, a Human Factor expert was included in the Safety Case production team.

2. Approach to the management of human errors in the FSC

It was sooner realised that the identification and management of all potential human errors in the Safety Case would be a complex and time-consuming activity if the traditional 'task list prioritization' process was followed. Therefore, it was considered convenient to follow an 'outcome-based approach', thereby limiting the analysis to the most critical MAH scenarios. This approach has both advantages and shortcomings in comparison with other approaches. This was comprehensively analysed in several papers and will not be repeated here.

Since the execution of step 3 was planned to be conducted using the Bowtie methodology, the decision was taken to also use the Bowtie methodology for the management of human errors by conducting Human Factors Bowtie Workshops based on the latest recommendations on the subject.

The MAH scenario FMAH-9 "Loss of containment of Liquid Chlorine Tank" is selected here for illustration purposes to show how the methodology was applied. This MAH represents the biggest on-site hazard of all MAH scenarios with high inherent risk (see Table 1). This scenario was developed with the assumption that a loss of offsite power occurs coincidentally. Tasks related to this scenario are prioritised for review over tasks related to other MAH scenarios.

Table 1. MAH scenarios considered as most critical for the Chlor-Alkali Plant

No.	Code	PMAH	Top Event	Consequences	Inherent Risk
1.	FMAH-9	Chlorine under pressure inside liquid chlorine storage tank	Loss of containment of storage tank	Escape of chlorine gas to atmosphere	HIGH
2.	FMAH-10	Chlorine confined inside a filling pipe	Loss of containment of chlorine filling pipe	Escape of chlorine gas to atmosphere	HIGH
3.	FMAH-11	Chlorine confined inside a container	Loss of containment of a container during filling operations	• Escape of chlorine gas • Spill of liquid chlorine	HIGH
4.	FMAH-13	Large amount of chlorine waste gas in the system	Insufficient chlorine waste gas absorption during emergencies	Escape of chlorine gas to atmosphere via vent	HIGH
5.	FMAH-16	Presence of hydrogen inside the system	Formation of explosive mixture in the synthesis unit	Hydrogen explosion in the system	HIGH
6.	FMAH-17	System working under slight pressure	Loss of containment in the Synthesis burner	Escape of HCL/Cl_2 to the environment	HIGH
7.	FMAH-25	Equipment that require power supply	Loss of external power supply	Various potential consequences, including escape of chlorine	HIGH

3. Process for managing human error risk

A systematic and auditable process was followed with clear links between SCTs and plant MAH scenarios. This consisted of the following steps (see fig.1) which are briefly described below:

- Step 1. Identification of safety critical tasks (SCTs)
- Step 2. Identification of error potential
- Step 3. Identification of Performance Shaping Factors (PSFs)
- Step 4. Evaluation of existing control measures
- Step 5. Development of additional control measures
- Step 6. Review of draft Bowties level 0,1 and 2 with Operator's technical and management staff

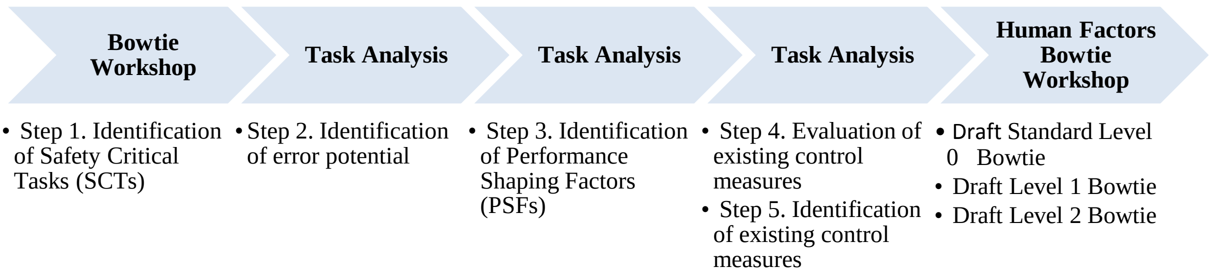

Fig.1 Process for the management of human error risk using Bowtie

3.1 Step 1. Identification of safety critical tasks (SCTs)

To achieve the active involvement of the Operator’s staff in the identification, analysis and management of human errors, a training course was delivered by the HF expert to both managers and workers with the aim of familiarizing them with the concept of human factors, and basic approaches to their assessment. The content of the training session addressed the following themes:

- Evolution of safety and human factors approaches
- Safety Culture
- Human error and Performance Shaping Factors
- UK HSE Top 10 Human Factors
- Human error identification and analysis techniques
- Practical group exercises

The identification of SCTs was carried out during the Step 3 Bowtie Workshop. Barriers that relied on human performance and degradation factors associated with human errors were reviewed to identify safety critical tasks (SCTs). Safety Critical (human) tasks were defined as ‘those activities people are expected to perform as barriers against the occurrence of an incident, or to prevent escalation in the event that an incident does occur, including activities required to support or maintain physical and technological barriers’(OGP, 2011). A total of 23 SCTs were identified for the scenario. These are shown in Table 1 below.

Table 1. List of SCTs identified for the FMAH9 scenario “Loss of containment of chlorine storage tank”

Task No.	Name
SCT9-01	Monitor and control of filling process as per Tank filling procedure
SCT9-02	Regular maintenance and testing of overfilling protection interlock as per Performance Standard (PS) – SD 001
SCT9-03	Regular check of Chlorine Tank pressure
SCT9-04	Operator response to high pressure alarm in the receiving tank
SCT9-05	Maintenance and testing of high pressure alarm in the receiving tank
SCT9-06	Maintenance and testing of Tank safety valves a per PS PC 007
SCT9-07	Detection and isolation of small tank leaks
SCT9-08	Quality Control (QC) of brine
SCT9-09	Regular monitoring and analysis of NCL_3 concentration in liquid chlorine
SCT9-10	Purging and destruction of NCl_3
SCT9-11	Checks for presence of oil/organic products
SCT9-12	Verification/gas-testing of joints
SCT9-13	Maintenance and testing of Tank overpressure protection interlock as per PS SD 001
SCT9-14	Checking of dew point
SCT9-15	Maintenance and testing of dry air dew point interlock
SCT9-16	Setting isolations for maintenance
SCT9-17	Corrosion inspection
SCT9-18	Chlorine gas detection
SCT9-19	Emergency shutdown of electrolysers
SCT9-20	Emergency isolation of chlorine storage tanks
SCT9-21	Transfer of chlorine to emergency tank
SCT9-22	Water curtain activation
SCT9-23	Start-up and line-up of emergency blower

3.2 Step 2. Identification of error potential

Unfortunately, it was not possible to engage Operator's staff at this step. It was realized that the analysis of SCTs was a complex activity requiring special skills. Therefore, the consideration of error potential associated with identified SCTs was considered separately by the HF expert by applying task analysis techniques for detailed description of the task steps and facilitating the identification and classification of potential errors.

Due to exiting constraints with the operational and maintenance procedures – they were non-existent or too general - it was not possible to analyze each task step. The whole task was then considered to be safety critical and errors were identified in relation to the entire task execution. To facilitate the identification of appropriate controls, errors were classified according to their type and the human processing involved. Two types of errors were defined: errors of omission and errors of commission, which could be of either manual or cognitive type.

3.3 Step 3. Identification of Performance Shaping Factors (PSFs)

This activity was carried out by the HF expert in isolation. During the detailed analysis of SCTs familiarization with the environment in which these activities were expected to occur was undertaken (control room or field). Unfortunately, critical locations like the control room were still under construction and many important control and monitoring equipment belonging to the man-machine interface were not installed or fully operational. This limited the possibility of carrying out a walk-through of the Control Room. In similar fashion, managerial aspects were difficult to assess. Notwithstanding, the identification of factors likely to affect human performance during the execution of those SCTs (Performance Shaping Factors) was carried out. For the PSFs the following classification based on groups was used (Table X) which provides examples of PSFs:

- People-level PSFs – Factors associated with the person who carries out the task
- Job level PSFs – Factors associated with the task
- Organization-level PSFs. – Organizational factors.

Table 1. Examples of Performance Shaping Factors (PSFs)

People-level PSFs	**Job-level PSFs**	**Organization-level PSFs**
Knowledge	Human-machine interfaces	Organizational Culture
Competence	Workload	Organizational Priorities
Skill	Procedures	Resource availability
Attitude	Task requirements	Communication systems
Physical capabilities/limitations	Relationship with co-workers	Policy and direction
Psychological health	Relationship with supervisors	Leadership commitment
Physical health (disease, medication, fatigue, substance abuse, etc.)	Physical environment (noise, lighting, vibration, temperature, humidity, etc.)	Workforce planning

3.4 Step 4. Identification of existing control measures

This step was carried out by the HF expert in isolation. For each relevant PSF, existing controls were evaluated by the expert to determine their ability to eliminate the risk posed by the PSF or to prevent it leading to error. Similarly, for each potential consequence of error, existing controls were evaluated to determine their ability to prevent and mitigate that consequence.

3.5 Step 5. Develop additional control measures

This step was carried out separately by the HF expert. Where it was identified that existing controls do not reduce error risk to a level that is ALARP, additional controls were suggested for review and approval.

3.6 Step 6. Review of draft Bowties level 0, 1 and 2 with Operator's staff

Step 6 allows analysis and management of human errors with involvement of Operator's staff during Human Factors Bowtie Workshops by using Human Error Layered Bowties (as recommended by CCPS and CIEHF), with bowties at lower levels being developed to give progressively more detailed attention to how human error can defeat barriers, and the safeguards that need to be put in place to mitigate against this possibility.

3.6.1 Draft Standard (Level 0) Bowtie

Fig. 2 shows extracts of the draft Level 0 Bowtie displaying degradation factor and safeguards for the barrier "MB 15.6 Operator response – Start-up and line-up of emergency blower to waste gas dechlorination unit".

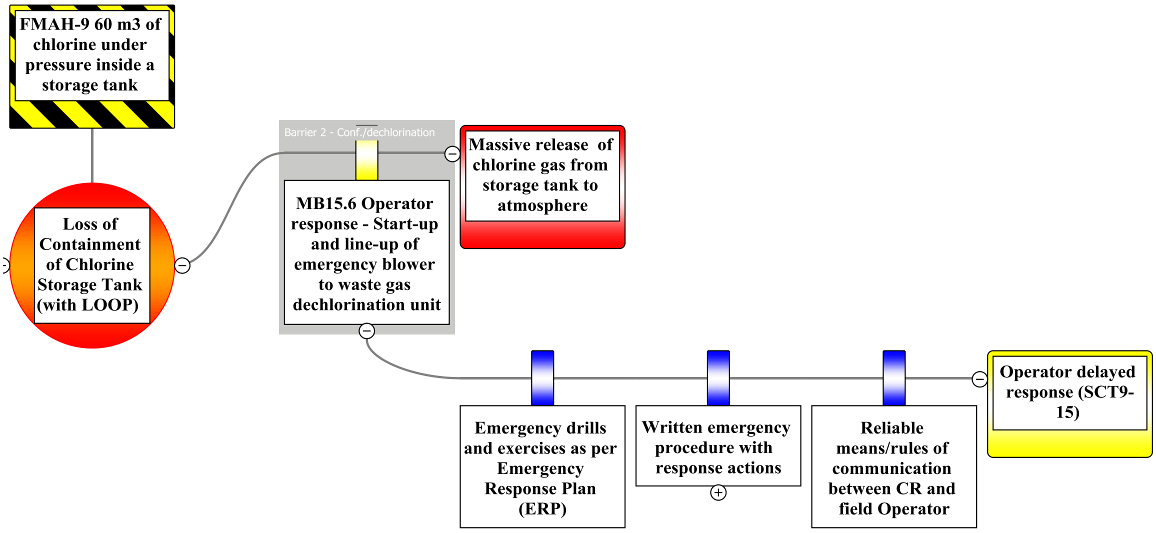

Fig.2 Level 0 Bowtie – Example of degradation factor and safeguards for the barrier "MB 15.6 Operator response – Start-up and line-up of emergency blower to waste gas dechlorination unit"

3.6.2 Draft Extension Level 1 Bowtie

Draft Level 1 Bowties were prepared based on the information regarding degradation factors/human errors, and associated safeguards identified in Level 0 Bowtie and the results of the walk-through review both at CCR and in the field.

Fig. 3 shows extracts of the draft Level 1 Bowtie displaying degradation factor and safeguards for the safeguard "Written emergency procedure with response actions".

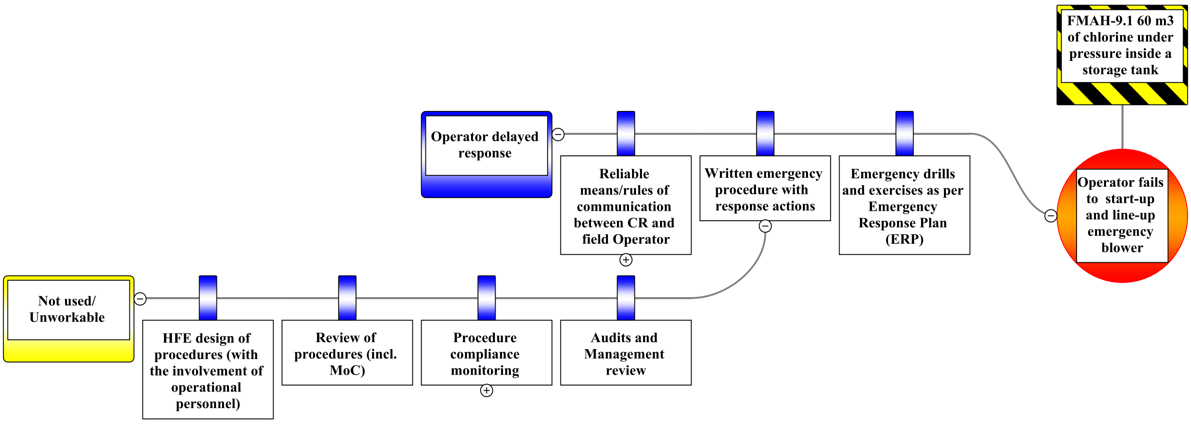

Fig.3 Level 1 Bowtie – Example of degradation factor and safeguards for the safeguard "Written emergency procedure with response actions"

3.6.3 Draft Extension Level 2 Bowtie

Draft Level 2 Bowties were then prepared based on:

- Information regarding degradation factors and associated safeguards from the Level 1 Bowties
- Results of the assessment of the Operator Organization's Safety Culture with the aim of identify shortcoming and areas potential areas of improvement.

Fig. 4 shows an extract of the Draft Level 2 Bowtie displaying the degradation factor and safeguards for the safeguard "Procedure compliance monitoring"

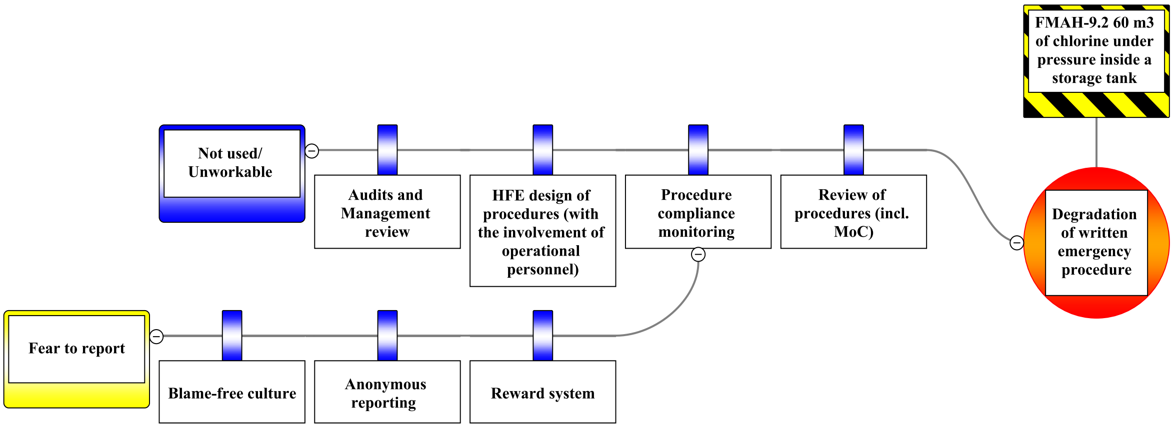

Fig.4 Level 2 Bowtie displaying degradation factor and safeguards for the safeguard "Procedure compliance monitoring"

3.6.4 Human Factors Bowtie workshops (HFBTW)

Draft Level 1 Bowties will be reviewed with responsible/knowledgeable (O&M) personnel to agree on identified safeguards and identify any additional safeguards, where it is identified that existing controls do not reduce error risk to an ALARP level.

Draft Level 2 Bowties will be reviewed with senior management to agree on identified safeguards and to identify any additional safeguards, where it is identified that existing controls do not reduce error risk to a level that is ALARP.

Draft layered Bowties captured deeper range of human and organizational factors and will be reviewed at the Human Factors Bowtie Workshops which will be carried out later with the involvement of Operator's staff with the following purposes:

- Agreement on identified degradation factors and safeguards
- Confirmation of the safeguards as being capable of preventing human error from happening
- Rating the actual effectiveness of safeguards
- Linking safeguards to responsible persons, management and administrative policies and procedures
- Confirming the validity of recommended additional control measures

Layered Bowties (Levels 0,1 and 2) which will be reviewed at HFBTW. These are limited to the following barriers (Level 0 Bowtie):

- High pressure alarm in the receiving tank and operator response
- Detection and isolation of small leaks
- Measurement and destruction of NCl_3
- Setting isolations for maintenance
- Chlorine gas detection and:
    - Emergency shutdown of electrolisers
    - Isolation of storage tanks
    - Transfer of chlorine to emergency tank
    - Activation of water curtains
    - Start-up and line-up of emergency blower

5. Recommended improvement actions for managing human error to ALARP.

Human Factors Bowtie Workshops have not yet been conducted, but once they have taken place they will provide and agree on many recommendations to enhance the capability of the Operator's organization to manage the risk of human error.

Notwithstanding, task analysis resulted in a number of recommendations in relation to the following aspects:

- Preparation of the Operator's Major Accident Prevention Policy (MAPP)
- Preparation of training programs for operating and maintenance personnel based on identified safety critical tasks

- Linkage of safety critical task performance with competence assurance
- Consideration of safety critical tasks when drafting operational and maintenance instructions
- Elaboration of checklists to reduce the impact of human errors of omission
- Human Factors Engineering (HFE) review of the Control Room and Worksites to reduce the impact of PSFs associated with the man-machine interface and work environment
- Implementation of a Safety Culture program to reduce the impact of both organizational and individual factors that influence safe behaviours.

6. Conclusions

This pilot study used a mixture of standard methods used for human factors task analysis and Bowtie development, however the actual involvement of the Operator personnel in the task analysis work was fairly minimal, with a lot of the work done by the HF expert. Although the latter seems unavoidable given the specialist nature of the tasks in hand and the present state of the facility.

It might be highly beneficial to investigate how both operators and maintenance personnel can become further involved in the analysis. For example, by direct involvement in the walk-and-talk through of the tasks. A key benefit of employee involvement is that personnel will be involved in the management of human error during the execution of day-to-day activities and appreciate the role of human factors in ensuring plant safe operation. This will also allow them to 'own' the safety case process and act as 'intelligent customers'.

In this regard, it is recommended that more development work is undertaken in terms of ensuring that the use of the Bowtie methodology incorporates human factors task analysis steps in a straightforward and 'user-friendly' way, leading to the generation of different layered Bowties for most critical degradation barriers and safeguards.

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